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Fusion Product Deposition and Energy Balance

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We have performed extensive Monte-Carlo calculations of alpha-particle deposition in the Hill's Vortex configuration, as reported in D.E.Driemeyer's Ph.D. Thesis (University of Illinois, 1980). This has generally been done including a cold plasma density, n_c, on the open field lines, with $n_C/T_C^{3/2} \cong n_H/T_H^{3/2}$ -- i.e. with the slowing down ratio τ_H/τ_c lying between .1 and 10. Since many of the alpha particles spend a significant amount of their time on the open field lines, values of τ_H/τ_C greater than unity lead to significant removal of alpha-particle "ash" from the closed-field region. Surprisingly, we are able to perform this ash removal and still retain enough energy to raise the reactor Q significantly (or even ignite it).

The fraction of alphas confined completely within the closed-field region, f_{CF}, and the fraction, F_{AC}, confined absolutely (including some excursions onto open field lines), are shown in Fig. 1. It turns out that we can write excellent correlation formulae:

$$(1^a) \qquad f_{RE} = f_{CF} + f_{MCE}(f_{AC} - f_{CF}) \text{ -- Retained Energy}$$

$$(1^b) \qquad f_{RP} = f_{CF} + f_{MCP}(f_{AC} - f_{CF}) \text{ -- Retained Particles}$$

for the retained alpha energy and particle fractions. We find

$$(2)^a \qquad f_{MCE} = -.4288 \log \frac{\tau_H \; E_D}{\tau_C \; \log(E_0/T_i)} + .2504$$

$$f_{MCP} = -.3501 \log \frac{\tau_H \; E_D}{\tau_C \; \log(E_0/T_i)} + .3450$$

These formulae correlate a large number of Monte Carlo results for both alpha particles and 14 MeV proton deposition in advanced-fuel reactors.

Figure 2 shows details of the correlation, and Figs. 3-5 show the reactor energy-gain values computed by incorporating $(1)^a$ - $(1)^b$ into an energy balance code which includes neutral-beam and axuiliary heating, classical or enhanced particle losses (at the user's option -- cf Fig. 3 vs Fig. 4), bremmstrahlung losses, and beta-corrected synchrotron radiation losses. Even for advanced fuels, the results are encouraging.

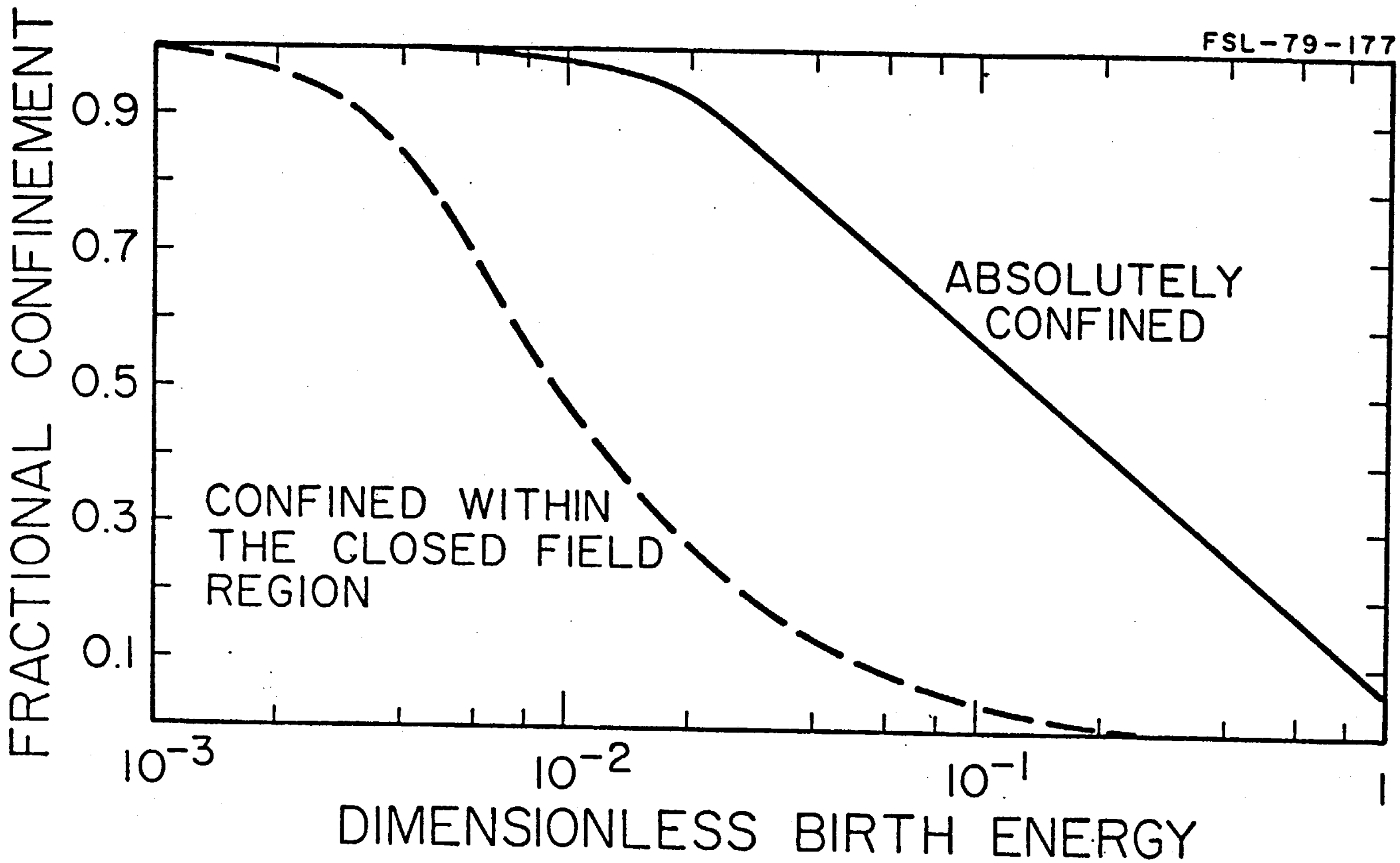

Figure 1 Confinement limits for fps in the FRM as a function of their dimensionless birth energy $mc^2E_0/(qB_0R_{HV})^2$. The upper "absolutely confined" curve corresponds to the fraction of fps that have $E < -P_\theta$, while the lower curve corresponds to those that, furthermore, have $\sqrt{2E} < -P_\theta$

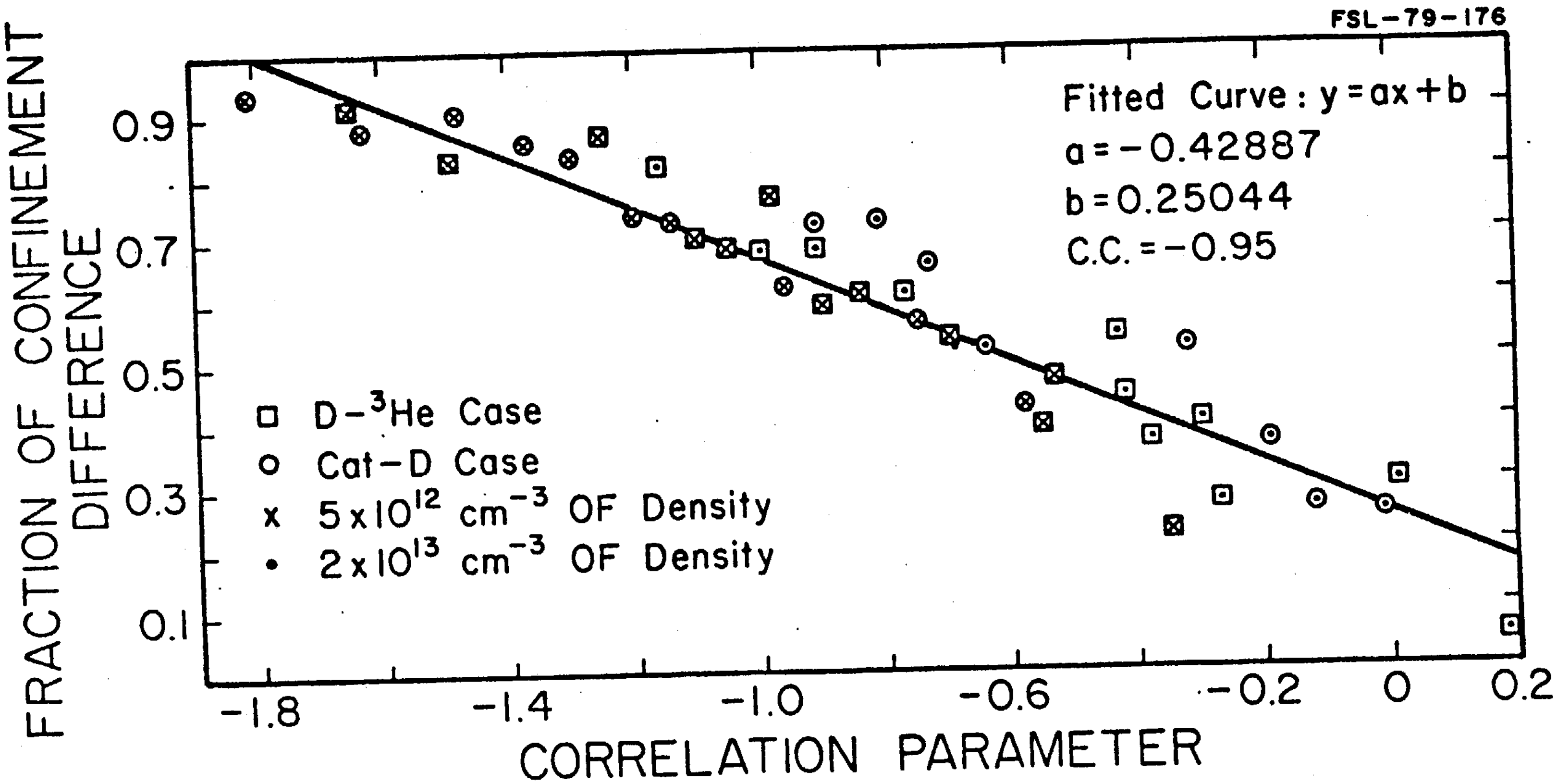

Figure 2 Correlation of the MCFRM results for the fracture of the marginally confined fp energy that is deposited in the closed field region for typical FRM plasmas. The correlation parameter is log $[(\tau_H/\tau_C)E_D/\log(E_0/T_i)]$ and the correlation coefficient is -0.95. The line is used to estimate fp energy deposition in the FRMOD code.

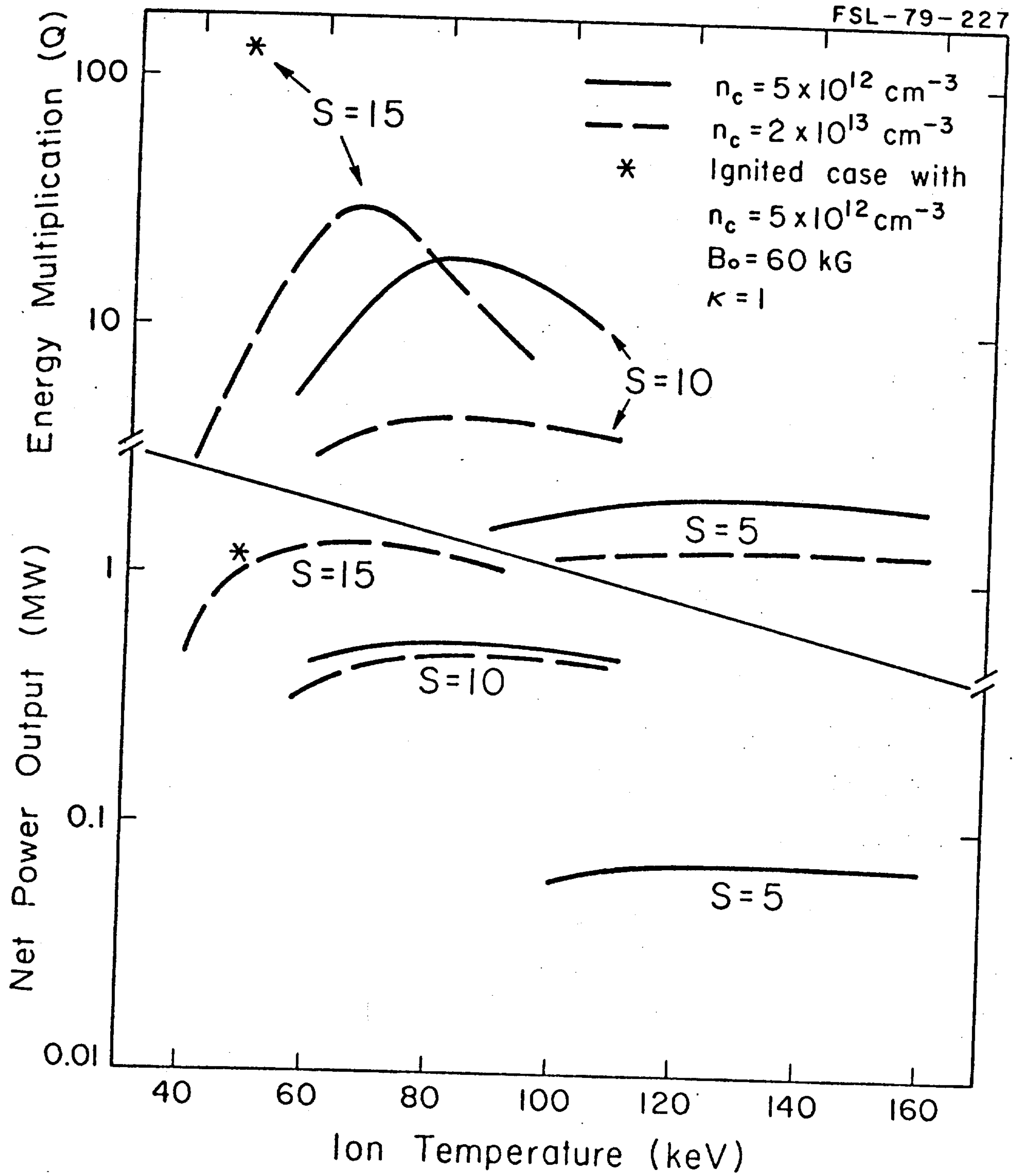

Figure 3 Energy multiplication factor and net power output vs the plasma ion temperature for D-^{3}He systems with "near-classical loss rates ($\tau_{particle}$ - $\tau_{class}/3$). n_e = density of s = a/ρ_i = ratio of density scale length to vacuum-field gyroradius at given ion temperature.

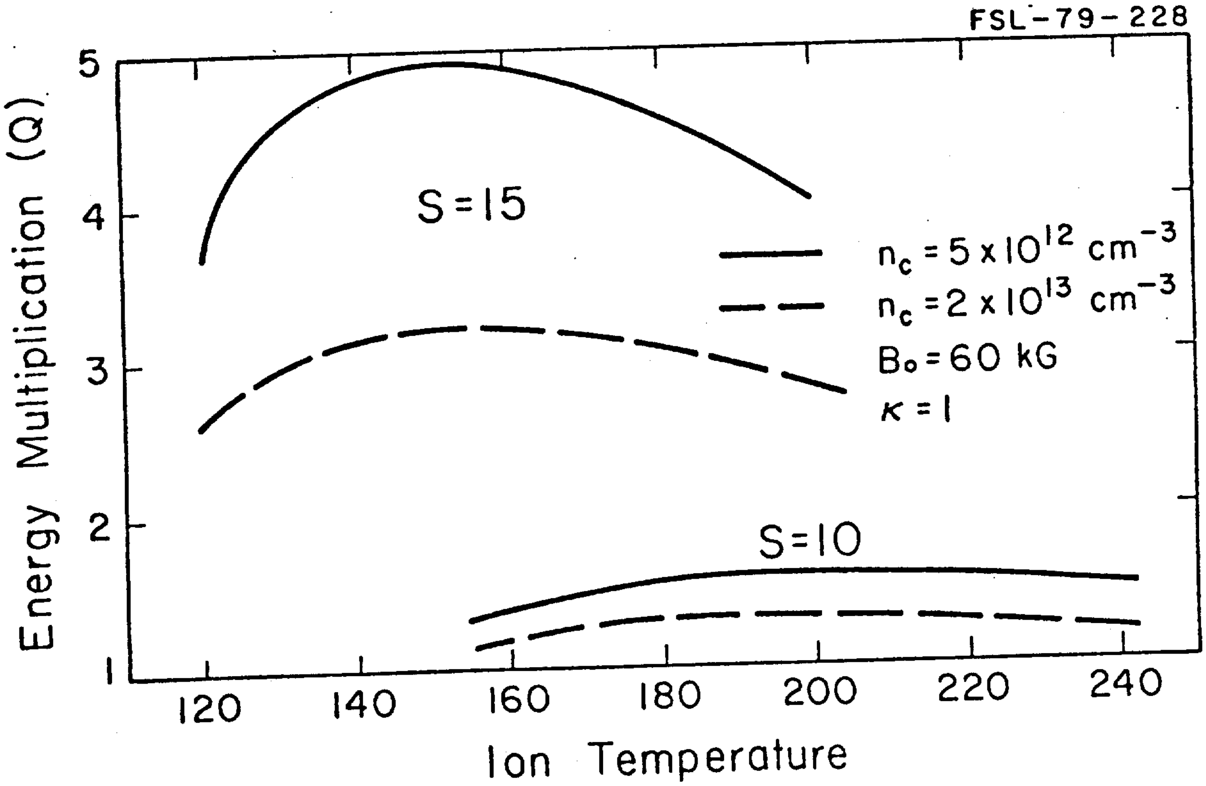

Figure 4 Energy multiplication factor vs the plasma ion temperature for D-^{3}He systems with anomalous loss rates.

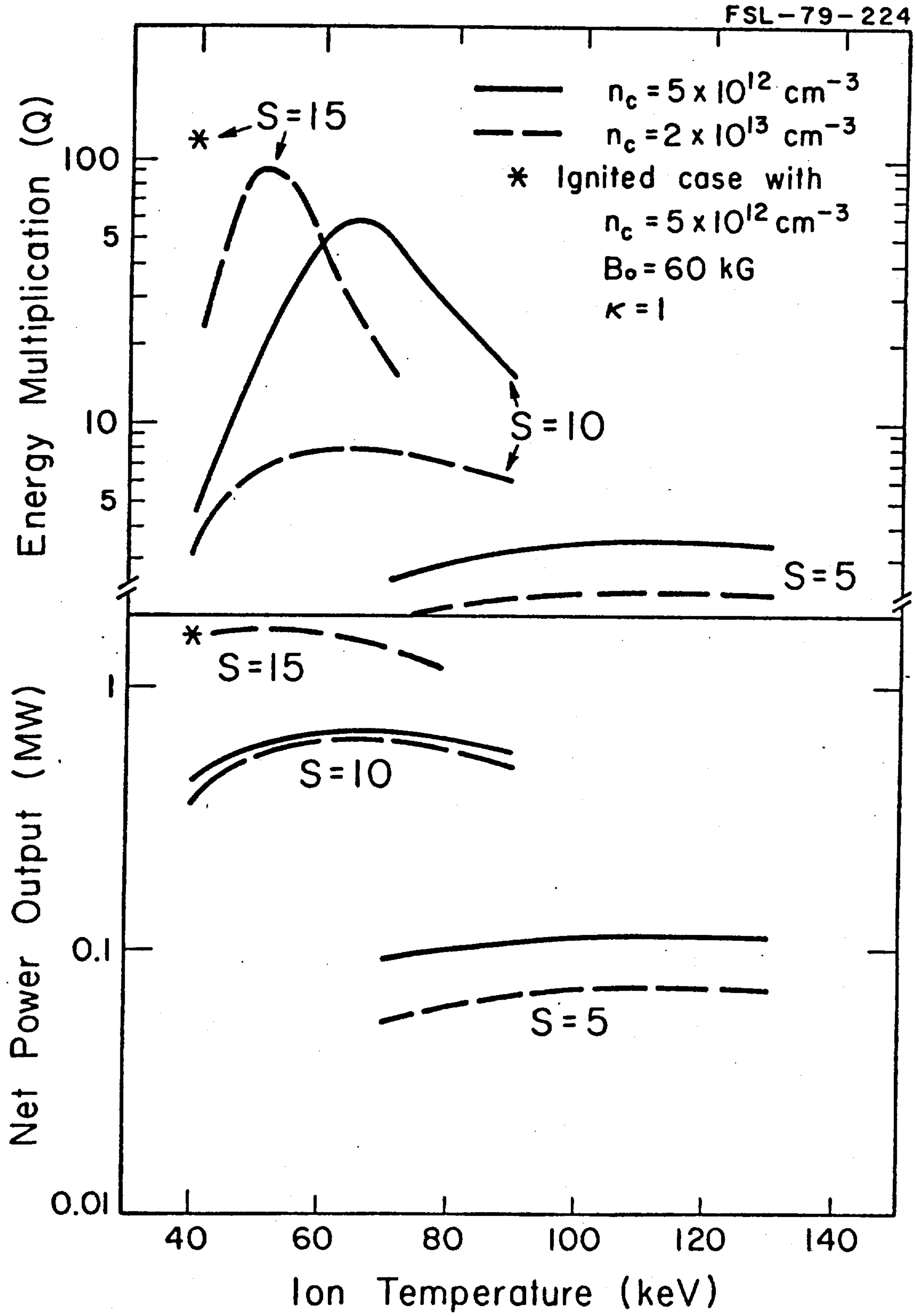

Figure 5 Energy multiplication factor and net power output vs the plasma ion temperature for Cat-D systems with "near-classical" loss rates. n_c = density of cold "scrape-off layer" outside separatrix.